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The estimation of the service areas of medium and long-wave broadcasting stations

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Summary

The aim of this report is to enable persons having no previous experience of the subject to make reasonable accurate estimates of the service areas of medium- and long-wave broadcasting stations, taking account of the vertical and horizontal directivity of the transmitting installation, its radiation efficiency, and the influence of the ground constants and of interference from other transmitters. It is not intended that the simplified skywave field strength prediction curves in this report be used for international planning; for this the appropriate internationally agreed methods must be used.

Issued under the authority of

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THE ESTIMATION OF THE SERVICE AREAS OF MEDIUM- AND LONG-WAVE BROADCASTING STATIONS

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1. Introduction

The service area of a broadcasting station may be defined, generally, as the area surrounding the transmitting site within which a signal of acceptable quality and freedom from interference can be received. Often the reliable service area of a station is considerably greater by day than by night, it being limited only (though sometimes seriously) by man-made electrical interference, natural 'atmospheric' interference or, at a lower level, by the noise generated in the receiver itself. At night, service areas are often considerably restricted by the interference propagated indirectly via the ionosphere, either from the station under consideration itself – causing fading and distortion – or from others on the same or nearby frequencies. Exceptionally, there may even be some restriction of the day-time service area of a station due to the presence of another transmission on or near the same frequency.

Medium- and long-wave broadcasting stations can also be received with an acceptable standard of quality over quite large distances at night and within a range of fading which does not detract too much from the acceptability of the service for some purposes e.g. news, light music or entertainment. This service area is sometimes called the secondary service area or 'sky wave' service area and will, in general, have the shape of an annulus surrounding the transmitter site. The use of the term 'secondary service area' is not recommended as this expression is sometimes used for the outer part of the day-light service area. Where estimates of service area involving the presence of indirect waves reflected from the ionosphere are required, the methods will be most accurate in temperate zones of the world, where conditions are similar to those in Eurpoe. In tropical regions or in high latitude areas and in cases where very high power is to be used, reference should be made to available papers[1,2] dealing with these cases.

The first step in assessing the limits of a service area is the preparation of a map showing the position of a number of field-strength contours of the ground-wave. From a knowledge of the level of interference and degree of fading it is then possible to mark directly on the field contour map another line defining the limit of the service area. Later, if required, a count of the total population within this boundary can be made.

1.1. Data required for calculation

Before a calculation of the approximate positions of the ground-wave field-strength contours can be undertaken the following information must be obtained or an estimate made. Section 2 deals with the use of this information and methods of estimation.

i) The position of the transmitter site, generally available as latitude and longitude or as a 'grid reference'.

ii) The working frequencies for which the ground-wave field-strength contours are required.

iii) The radiated power of the station and information on the directivity of the aerial system in the horizontal and vertical planes.

or

iv) Values of the unattenuated field-strength at unit distance in all directions in the horizontal plane.

v) The effective ground conductivity at the working frequency in all directions.

The other facilities then required will be maps of suitable scale for the purpose, geological maps in certain cases and an atlas of standard curves of ground-wave propagation giving field-strength/distance curves for various values of ground conductivity and frequency. A suitable atlas of curves is provided with Recommendation No. 368–2 of the CCIR.[3] To facilitate estimation of service areas on the long- and medium-wave broadcasting bands suitable curves, as regards frequency, range of distances and range of ground conductivities have been copied from the CCIR data and are attached, as Figs. 2–6.

2. Procedure for the preparation of maps showing the position of ground-wave field-strength contours

The following procedure should be followed:–

i) Choose a map of suitable scale for the power and frequency of the transmitter under consideration using the following general principles. For high powers of 100 kW or more the scale could be about 1 : 1,000,000 for a long-wave station; e.g. the whole of the United Kingdom on one sheet. For a medium-wave transmitter a scale of about 1 : 500,000 is suitable. For the contours of a low-power station of 1 kW or less a scale of 1 : 250,000 or an even larger scale, is convenient. In preparing a detailed field-strength contour map of the highest accuracy it is probably best to use initially a larger scale map and later reduce the scale of the final map with the plotted contours; this is convenient if, for example, many copies are required for distribution.

ii) Mark the position of the transmitter site clearly on the map, using the given co-ordinates or grid reference. Most sites also have a name, generally that of the nearest town or village and this should be checked against the co-ordinates or grid reference.

iii) Draw a series of radial lines in pencil outwards from the transmitter site to the boundaries of the map. The number of radials required to give a good representation of the field-strength contours will depend upon the following two factors:

a) Whether the horizontal radiation pattern of the transmitting aerial system is uniform in all directions (known as omnidirectional), or is intentionally directional, or distorted by the effect of supporting masts or other aerials in the vicinty.

b) The degree of variation of the ground conductivity around the transmitting site.

Where there is a considerable variation of either horizontal directivity or conductivity in different radial directions, a fairly large number of radial lines, even up to 10 or 12, should be drawn but judgement must be used in selecting the best actual directions of the radials, which need not be uniformly spaced in angular direction. If, for example ground conductivity is known to be uniform over a large sector then one or two radials only need be drawn in that sector but where there are large changes in conductivity more radials should be drawn. Similarly, where the ground conductivity around a site is fairly uniform but a directional transmitting aerial is proposed or in use, only a few radials need be drawn in the directions corresponding to a flat maximum of the horizontal radiation pattern but a greater number in directions around a rapidly changing minimum.

Often a quick, though not very accurate estimate of the field-strength contours can be made on the assumption that the ground conductivity is uniform in all directions out to the limits of the service area. A single radial can be used for marking off the field-strength contour positions which are then drawn in as circles when an omnidirectional transmitting aerial is used. Estimates of contour positions made in this way are likely to be more accurate at the lower frequencies and in areas where there are obvious changes in the nature of the terrain. In the case of a low-power station, the outer field-strength contours of which do not extend very far in distance, it can often be assumed that the ground conductivity is uniform and the time taken to plot the field-strength contours can then be much shortened by the method described in Section 2.6.

iv) Estimate the effective conductivity of the ground along the various radials selected for plotting the field contours under (2.3) above.

Although the values of ground permittivity ϵ (dielectric constant) also vary over a considerable range, insignificant errors in calculation arise at m.f. and l.f. over the distances with which we are usually concerned with broadcasting, if constant values are taken for land and water separately. The CCIR curves[3] are drawn for $\epsilon = 4$ (land) and $\epsilon = 80$ (water).

There are two ways of making the necessary estimate of conductivity.

a) By the use of measurement data from earlier experiments.

In the case of the United Kingdom a considerable amount of such data has been accumulated over past years enabling a value of conductivity around many of the existing sites to be deduced. It should be mentioned here that effective ground conductivity is often found to vary appreciably with frequency, generally increasing with frequency though not in direct proportion. The effect is believed to be due to the stratification of the ground, the top layers being generally moist soil of relatively good conductivity overlaying the rock sub-strata of relatively poor conductivity. The map, Fig. 1, gives an indication of the average ground conductivity in various areas of the United Kingdom, and has been derived from measurements, mainly at m.f. It must be borne in mind that a small-scale map of this kind does not show small areas of higher or lower conductivity. In all cases the best estimate of conductivity will be made when the information on the map is combined with an estimate made after inspection of relief maps and geological maps, some allowance being made for exceptional features of either relief or geology.

b) By comparison of the known geology of the surface and sub-strata with similar strata for which the conductivity is known.

This method has to be adopted when estimates are required for country for which no conductivity maps are available. Research Report No. K-062, Serial No. 1944/10 'Some measured ground conductivities in the British Isles and their geological correlation' will be found to be useful in this respect and in some text books a general indication of conductivity over typical country, e.g. mountanious, pastoral etc., can be found.[4] Factors determining ground conductivity and methods of measurement are fully discussed in a CCIR Report.[5]

Conductivity values are currently given in the appropriate S.I. unit, namely Siemens/metre, this being in effect identical to the earlier m.k.s. unit (mho/metre). Older literature may quote conductivity in electromagnetic units (e.m.u.) where 10^{-11} e.m.u. = 1 Siemens/metre.

In the absence of measured data, judgement is required to estimate effective ground conductivity and when reference is made to Report No. K-062 it may be decided that the appropriate value lies somewhere between the four values for overland paths, for which the standard field-strength/distance curves are plotted in Figs, 2–6. In this case it is generally best to use the standard curve for the nearest lower value of conductivity to the estimated value. In plotting the final service area map it is best to err on the pessimistic rather than the optimistic side.

v) Assess the power and aerial directivity correction to be applied to the standard field-strength distance curves of Figs. 2–6.

The curves of Figs. 2–6 give field-strength values at a given distance for the case of a short vertical aerial, radiating a power of 1 kW, that is for an aerial giving a field strength of 300 mV/m at 1 km over perfectly-conducting ground. This is also known as a cymomotive force (c.m.f.),* of 300 Volts. Other aerials and powers will give other values of c.m.f. and the appropriate values must be calculated and a suitable correction factor derived.

Assessment of the power and aerial directivity corrections can most reliably be made by field strength measurements to determine the c.m.f. on particular bearings. Measurements made on the required radial are plotted to give a curve of field strength x distance versus distance. The relevant c.m.f. is obtained by extrapolation to zero distance. A more accurate method of deriving c.m.f. from radial field strength measurements is given in Research Department Report RA-130.[6]

If field strength measurements cannot be made assessment of the power and directivity corrections can be assessed by one of the following methods.

a) Very often the transmitter output power only is given, together with some general information about the type of aerial to be used, e.g. short 'T' aerial on low masts, mast radiator of given height, etc.

An allowance must first of all be made for the loss of power in the feeder, aerial coupling circuit and in the aerial itself, other than by radiation. Of these the first two are small, generally much less than 1 dB, and may often be regarded as negligible. The aerial loss, due to all components of the total aerial resistance except that due to radiation, can be a considerably proportion of the total, where either the radiation resistance of the aerial is not very large, as in the case of a short vertical, or where the earth system is inadequate. As a result of either or both of these factors the 'aerial radiation efficiency' may be low, even less than 50%. Accurate assessment of the efficiency factor requires a measurement of the series total resistance of the aerial at the feed point and a calculation of the radiation resistance. Alternatively, if neither can be measured an estimate must be made.[7]

A combined power and aerial efficiency correction factor, G, can be expressed thus:

$$G = P_T + 10 \log_{10} Y + D \text{ dB}$$

where P_T is the known available output power of the transmitter dB rel. 1 kW

Y is the overall aerial efficiency, including all feeder coupling and other losses, expressed as a decimal.

D is any gain expressed in dB, due to intentional or unintentional directivity of the aerial in the horizontal or vertical plane, referred to the case of a short omnidirectional aerial.

b) In other cases the design data of the transmitting aerial may include horizontal and vertical radiation patterns giving relative values of field-strength referred to a 'unit' level, the unit level being defined as the unattenuated field-strength at 1 km distance (c.m.f.). The gain factor, G, in decibels to be applied to the standard curves will then be given by:

$$G = 20 \log_{10} \frac{\text{c.m.f. x R}}{300}$$

where R is relative field strength in any required direction. Alternatively c.m.f. might be specified in different directions, in which case R would not be required.

vi) Where it is apparent the ground conductivity is uniform along any radial drawn on the map the field-strength at any particular may now be read off as follows:

Select the appropriate field-strength/distance curve from Figs. 2–6 as regards frequency and ground conductivity. For any chosen direction add the power and aerial directivity gain to the value of field-strength given by the ordinate scale. By taking a series of convenient distances a new field-strength/distance curve can now be constructed for each radial direction. The distances at which the required field-strength contours are reached are then noted, transferred to the map and contours of equal field-strength finally drawn in.

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*Cymomotive force represents numerically the limiting value of the product of field strength and distance from the transmitter as the distance is reduced to zero and has the dimensions of voltage.

It is often found that the ground conductivity is not uniform along a selected radial drawn on the map. If the differences are not great, e.g. a change from an area marked as 4–8 milli Siemens/metre (mS/m) to 10–15 mS/m, it is generally sufficient to estimate an 'average value' say 10 mS/m in this case. Where, however, the differences are large, a more complicated procedure, known as a 'mixed-path' calculation must be used. This condition will quite often apply in countries such as the United Kingdom where there are considerable changes of ground conductivity and where over-sea paths are frequently encountered. The procedure recommended for the mixed-path calculation of field-strength is that known as the 'Millington Method'.[8] The CCIR also recommend the use of this method.

Application of the 'Millington Method' may be explained by reference to Fig. 13 in which it is assumed that a mixed path of total length d comprises two sections d_1 and d_2 having, respectively, conductivities σ_1 and σ_2 where $\sigma_1 > \sigma_2$. To ensure that reciprocity requirements are met it is necessary to calculate the field strengths obtained by traversing the path in both directions and then to obtain the average.

The calculation in the 'forward' direction is represented in the upper part of Fig. 13, which shows the field strength/distance curves for the two conductivities at the appropriate frequency. The field strength at any distance less than d_1 can be read directly from the curve for $\sigma = \sigma_1$; at any point beyond d_1 the field strength decreases at a rate given by the section of curve for $\sigma = \sigma_2$ from B to C, but commencing at the value given by point A. The variation of field strength in traversing the path in the 'forward' direction from T to R is thus given by the composite curve OAD.

The corresponding field strength obtained if the path is traversed in the reverse direction is calculated in an analogous manner as shown in the lower half of Fig. 13. The final result is then given by the mean of these two individual values, where all field strengths are in decibels relative to 1 μV/m.

After the above procedure has been followed using the curves for a c.m.f. of 300 V, the appropriate power and aerial directivity factors are added. This procedure may be extended to cover paths involving more than one change in conductivity, but if several changes are involved it becomes somewhat tedious to apply and other methods such as the 'Somerville' or equivalent distance method,[9] although a lesser accuracy, may be preferred. Also, although the Millington method can quickly be used to obtain the value of field strength at a known distance, the calculation of the distance at which a particular field strength occurs may involve iterative calculations.

3. Procedure for the determination of the limits of the ground-wave service area in the presence of interference or fading

As outlined in the introduction to this report, the limit of the service area is reached when the quality of reception is no longer acceptable and the service area therefore depends on a definition of acceptable quality. When the limit of service is controlled by radio noise or by radio-frequency interference from other transmissions the service area will be defined by the field-strength required to overcome the interference sufficiently. Because the interference itself may not be uniform over the whole of the service area of the wanted station, the required field-strength of the wanted station may differ with direction. In any case the service area will depend on the power of the wanted station.

If the limit of acceptable quality is reached only as a result of distortion due to the interaction of the 'sky-wave' with the ground-wave, the geographical limits of the service area will be determined by the relative strength of the ground-wave compared with the downcoming radiation from the ionosphere.

The procedures for calculating service area limits in the presence of interference or fading are listed below for each of a number of circumstances.

3.1. Service area limited only by fading of the wanted signal

The limit of service area is reached, at night, when the strength of the reflected wave from the ionosphere is just sufficient, with average modulation depth, to begin to cause a noticeable deterioration of quality for appreciable periods of time.

It has been found from long experience under practical conditions that at m.f. this limit of service area is reached when the ground-wave field-strength is just equalled by the field-strength from the reflected wave which would have been received via the E-layer of the ionosphere when the ionosphere is assumed to give loss-free reflection of all the power radiated upward from the transmitting aerial. This definition of the inner limit of service area will be seen to be reasonable when it is known that only very rarely in practice is the indirect ray received without attenuation during reflections. Experience again has shown that although undoubtedly perceptible distortion can occur from time to time at a point determined on the above basis, it does not persist for sufficiently long periods of time to cause listeners to complain. To assess the extent of a non-fading service area on the above basis we proceed as follows:

i) Plot the ground-wave field-strength contours by the method described in Section 2 above.

ii) Prepare curves of the sky-wave unattenuated field-strength in terms of ground distance, making allowance for the vertical radiation pattern of the transmitting aerial system in the appropriate horizontal direction and assuming an increase in the sky-wave field strength of nearly 6 dB* to result from additive combination of direct and ground reflected signal components at the receiver. These would correspond in general with each of the radials for which ground-wave calculations have already been prepared as detailed in Section 2. Quite often the vertical radiation pattern will not change appreciably with direction and the use of one or a very few curves for the sky-wave field-strength will then suffice.

If the transmitting aerial is known to be short in proportion to the wavelength ($h<\lambda/4$) the vertical radiation pattern can be assumed to follow a cosine law, i.e. the radiation at any given angle from the horizontal varies as the cosine of that angle.

In the case of vertical transmitting aerials, e.g. mast radiators which exceed $\lambda/4$ in height, allowance must be made for the vertical radiation pattern and suitable curves for this purpose are available or should be obtained from the designer of the aerial in special cases. Most vertical radiators are base driven and the curves of Figs. 7–12 give the values of sky-wave field-strength received at various distances. Figs. 7, 8 and 9 refer to a transmitting site surrounded by ground of good conductivity ($\sigma = 10^{-2}$ Siemens/metre) and Figs. 10, 11 and 12 refer to a transmitting site of poor conductivity ($\sigma = 10^{-3}$ Siemens/metre).

Other aerials commonly in use for l.f. and m.f. broadcasting are mast radiators with a capacity top or a 'T' aerial supported by two masts. Procedures are available[10] for calculation of the vertical radiation patterns of such aerials and curves similar to those given in Figs. 7–12 can then be prepared.

iii) By combining the curves obtained for ground-wave against distance and sky-wave against distance from 3.1.1 and 3.1.2 above, the point of equality can be read off and then marked on the service map as the point at which the service area begins to be limited by fading.

The curves of Figs. 7–12 can be used directly to find the limits of fading-free service area in cases where it can be assumed that the propagation path has a uniform ground conductivity. In such cases it is only necessary to select the appropriate curve for local conductivity and for the estimated overall ground conductivity along the transmission path. To avoid making the figures too complicated only three values for intervening ground conductivity have been shown on the figure, e.g. sea ($\sigma = 4$S/m), good ($\sigma = 10^{-2}$ S/m) and poor ($\sigma = 10^{-3}$ S/m) ground respectively. The distance at which the service area will begin to be limited by selective fading will then be given by the distance of the point of intersection of the appropriate ground-wave and sky-wave curve.

Experience has shown that in the l.f. band the limit of fading-free reception approximates more closely to the distance at which the loss-free sky-wave field strength exceeds the ground-wave field strength by 5 dB, rather than, as at m.f., to the distance at which they are equal.

3.2. Service area limited by a distant co-channel or adjacent channel station

To assess the limit of the service area under these conditions it will be necessary to assume a figure for the protection ratio required by the wanted signal. This protection ratio will be the field-strength ratio, expressed in decibels, of the wanted to the unwanted signal which will provide an acceptable grade of service. Protection ratios are largely determined by subjective tests and vary according to the type of programme on both the wanted and unwanted transmission and on the r.f. frequency difference between them. The characteristics of the receiver also affect the protection ratio when the wanted and unwanted transmissions are not on the same frequency, and in tabulating typical protection ratios the average effect on available commercial receivers is generally allowed for.

The CCIR recommends[11] that for co-channel transmissions which differ in frequency by less than 50 Hz the protection ratio " . . . should be 40 dB when both the wanted and the unwanted signals are stable (ground-wave). When the wanted signal is stable and the unwanted signal fluctuates (skywave), the radio-frequency protection ratio should be 40 dB at midnight for at least 50% of the nights of the year."

The EBU Technical Committee, whilst recognising that a co-channel protection ratio of 40 dB is desirable if interference is to be no worse than 'just perceptible' under the most stringent conditions, also recognise that this value represent a somewhat unrealistic planning standard to be applied to night-time services in the European Area. They have accordingly proposed a relaxation to 30 dB and this has been endorsed by the EBU Programme Committee.

If both the wanted and interfering transmitters carry the same programme and are 'synchronised' i.e. operate with r.f. carrier frequencies controlled to within a few tenths of a Hertz, then fairly low protection ratios are acceptable. Here also the nature of the programme is important but the required ratio is dependent also upon other factors such as the depth of modulation and any relative delay time between audio modulations. Typical required protection ratios for 'synchronised' operation are between 6 and 10 dB, the lower value relating to highly compressed continuous music of the popular type received on a typical transistor portable receiver.

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*The curve of Figs. 7–12 assume a ground reflection coefficient of 0·9.

For interfering transmissions not at the same nominal frequency as the wanted signal the concept of a relative protection ratio is useful. This is the protection ratio (at the stated frequency spacing) relative to that for co-channel interference which gives the same subjective reception impairment. Fig. 14 shows relative adjacent channel protection ratio curves recently proposed by the EBU and agreed by the CCIR. The protection ratio to be applied is thus obtained by adding the relative protection ratio given in Fig. 14 for the appropriate transmission characteristics and frequency separation to the value of co-channel protection considered to be the suitable planning standard.

Thus, for example, if 30 dB is considered to be the co-channel protection ratio, the protection ratio required for adjacent channel operation at 9 kHz channel spacing with bandwidth restriction and highly compressed modulation is:

$$30 + (-29) = 1 \text{ dB}$$

The corresponding value for adjacent channel at 8 kHz spacing is

$$30 + (-22) = 8 \text{ dB}$$

the former value relates to the channel spacing used over the l.f. band and most of the m.f. band in ITU Region 1;* the latter to the higher frequency end of the m.f. band (above 1538 kHz) in Region 1.

It may be seen from Fig. 14 that the reduction in protection ratio derivable from restricting radiated bandwidth is much less at small separations such as 8 kHz, for which adjacent channel interference is an important factor, than at greater spacings such as 9 kHz or 10 kHz.

Having decided on the appropriate protection ratio the limiting field-strength of the service area of the wanted station is obtained by adding the protection ratio to the field strength of the distant unwanted transmission, determined according to its distance by one of the following means.

3.2.1. When the interfering transmitter is at a distance of approximately 150–300 km

This condition will often be found within a single country where two transmitters separated by distances of the above order radiate a common programme, e.g. Droitwich 1052 kHz and Postwick 1052 kHz.

The first step is to derive, be means of one of the methods given in Section 2 curves of field strength against distance along each of several radials from the wanted transmitter. Initially it will be found convenient and may save time, if no great detail is required, to plot only for the two directions either directly towards or directly away from the interfering transmitter. On each of these curves an overlapping curve of sky-wave field strength from the interfering transmitter can be drawn using the appropriate curve from Figs. 7–12 and adding a correction factor for the power of the interfering transmitter.

If, as is usually the case at such distances, a common programme is radiated, the limit of service area of the wanted station is given by the points on the curves drawn as described above, where the ground-wave and sky-wave curves intersect, the condition for audible distortion being the same as in the case of the limitation of service area by the selective fading of the wanted transmitter. It may appear from the above that it has been assumed that the acceptable protection ratio for common channel working between transmitters spaced by distances of this order has been assumed to be zero. This is not actually the case, because with the method of calculating the sky-wave field-strength wave adopted it is assumed that the ionospheric wave suffers no attenuation whereas in fact the loss, variable through fading, would be of the order of 10 dB or more.

If the unusual case arose of co-channel transmitters within a distance range of 150–300 km radiating different programmes, it would be appropriate to calculate the sky-wave field-strength as above and then to allow the protection ratio minus an allowance of 10 dB for ionospheric loss to determine the service area of the wanted station.

3.2.2. When the interfering transmitter is at a distance of over 300 km

In this case also the limit of the service area of the wanted station is the field strength obtained by adding the appropriate protection ratio to the field strength of the distance interfering station. The level of this interfering sky-wave signal will vary according to systematic diurnal and seasonal trends and also, to a lesser extent, according to solar activity. Diurnal and seasonal corrections may be derived from Figs. 15a and 15b. Fig. 15a indicates times of local sunset and sunrise throughout the year as a function of latitude. Fig. 15b gives the required correction in decibels relative to a time well after sunset, or in effect, to the annual midnight median value of field strength. In using Fig. 15a it should be remembered that the relevant local time is that on the ground below the ionospheric reflection point; in the case of multi-hop paths, i.e. paths longer than about 2200 km it is the time at the reflection point for which the sun sets last and rises first.

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*This includes Europe

There will also be short-term random variations in the interfering field strength and sometimes these are taken into account by protecting the wanted service against the 'quasi-maximum' value of interfering field strength. Since however this is merely equivalent to protecting against a median value of interfering field strength at an appropriattely higher protection ratio it will be assumed hereafter that the interfering field strength is the midnight median value amended if required by diurnal and seasonal corrections.

Values of the midnight median field strength as a function of distance and of frequency are given in CCIR Report 264–2.[12] These curves were based on measurements within the European Area covering a distance range from 300 km to 3500 km, but further measurements extending to greater ranges have indicated that the curves tend to under-estimate field strengths at distances in excess of 2000 km. Other more recent methods are contained in a CCIR Report[13] and a sophisticated prediction method which takes account of all the various losses suffered by a signal in the path between transmitting and receiving aerials is described in Research Department Report RA-113.[14]

For accurate prediction recourse should be made to one of these recent methods,* but for more general use a simple frequency-independent empirical curve, which has been developed within the EBU, can be applied. This curve is reproduced in Fig. 16. Although derived only from measurements at m.f. this curve is also valid at l.f.

The reader is reminded that the curve in Fig. 16 represents the annual midnight median value of the sky-wave field strength. This is however, representative of conditions in mid-European latitudes for the evening listening period centred on 2100 hours local time during early autumn. For other times and seasons recourse must be made to the corrections given in Fig. 15.

3.3. Service area limited by the combined effect of a group of interfering transmitters

In general any transmitter will be subject to interference from several sources, although in many cases one source is predominant. The interference may be from either:

(a) co-channel transmitters radiating a different programme
(b) other transmitters in a synchronised group of which the wanted station is a member
(c) transmitters on adjacent channels

For each of these individual sources the value of interfering field strength should be calculated as previously described; e.g. using the skywave curves** of Figs. 7–12 for distances less than about 300 km, and that of Fig. 16 for greater distances. Addition of the relevant protection ratio then gives a value of field strength representing the minimum signal level protected against interference from each individual source (currently defined by the CCIR as the 'usable' field strength).

To obtain the effective overall usable field strength it is then necessary to add the effects of the various interferences. This is normally done by summing the individual usable field strengths on a power sum basis. Thus, for example, the effective level resulting from two equal contributions is 3 dB greater than each individual contribution. Fig. 17 represents a curve indicating the appropriate increase (in dB) for two sources as a function of their field strength ratios (also in dB). The figure may also be used, by successive additions, to calculate overall levels from more than two sources. The following example shows how such calculations may be carried out and indicates the general use of the various curves in this Report.

Example

Calculate the effective usable field strength (annual midnight median value) and service range for a 20 kW transmitter subject to the following sources of interference:

(i) member of the same synchronised group at distance 75 km (c.m.f. +10 dB relative to 300V)
(ii) member of the same synchronised group at distance 250 km (c.m.f. +17 dB relative to 300 V)
(iii) co-channel transmitter carrying different programme at distance 2000 km (c.m.f. +20 dB relative to 300V)
(iv) adjacent channel transmitter at distance 1000 km (c.m.f. +30 dB relative to 300V)

All transmitters are assumed to have short omnidirectional transmitting aerials, ground conductivity = 10^{-2} S/m. Frequency = 1 MHz. Protection ratios for (i) and (ii) to be 8 dB and for (iii) to be 30 dB. The relative protection ratio for (iv) to be –29 dB, i.e. a protection ratio of +1 dB.

Calculation

(a)	Skywave	
(i)	From Fig. 7	Interfering field strength = 59 + 10 dB (for power) – 10 dB (for ionospheric loss) = 59 dB (μV/m) Usable field strength = 59 + 8 = 67 dB (μV/m)
(ii)	As for (i)	Interfering field strength = 62 + 17 – 10 = 69 dB (μV/m) Usable field strength = 69 + 8 = 77 dB (μV/m)
(iii)	From Fig. 16	Interfering field strength = 26 + 20 (for power) = 46 dB (μV/m) Usable field strength = 46 + 30 = 76 dB (μV/m)
(iv)	From Fig. 16	Interfering field strength = 39 + 30 (for power) = 69 dB (μV/m) Usable field strength = 69 + 1 = 70 dB (μV/m)

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*The first session of the Regional Administrative l.f./m.f. Broadcasting Conference (Geneva 1974) agreed that the method detailed in CCIR Report 575 be used in Europe, Africa and Australasia.

**It may also be necessary, particularly for synchronised networks, to use Figs. 2–6 to determine whether interference by ground-wave is a significant factor.

(b) Calculation of multiple skywave:

From Fig. 17 summation of (i) + (ii) = 77 + 0·4 = 77·4 dB (μV/m)

summation of (iii) + (iv) = 76 + 1 = 77 dB (μV/m)

whence summation of (i), (ii), (iii), (iv) = 77·4 + ·2·8 = 80·2 dB (μV/m)

The groundwave service range for a 20 kW transmitter (c.m.f. + 13 dB relative to a c.m.f. of 300V) having a usable field strength of 80 dB (μV/m) is given in Fig. 4 by the distance at which the field strength equals

$$80 - 13 = 67 \text{ dB } (\mu\text{V/m})$$

For a frequency of 1 MHz this corresponds to a range of about 42 km.

(c) Groundwave

So far only interference by skywave has been considered but the possibility of interference by groundwave must also be explored. Examination of Fig. 4 indicates that only source (i) is likely to be of significance. Transmitter (i) will produce at the site of the wanted station (distance 75 km) a field strength of:

$$57 + 10 \text{ (for power)} = 67 \text{ dB } (\mu\text{V/m})$$

whence the usable field strength = 67 + 8 = 75 dB (μV/m)

This is not negligible relative to the level of skywave interference. Furthermore the groundwave interference level varies significantly over the nominal service range as determined by skywave interference, whereas the skywave interference level is relatively little affected.* This means that the service range is no longer constant in all directions but suffers the greatest restriction in the direction towards transmitter (i). The position of the limit of service can be predicted by calculations which include this ground wave interference. Thus at a point 30 km in the direction of (i), (distant 45 km from (i)), the level of groundwave interference is

$$65{\cdot}5 + 10 = 75{\cdot}5 \text{ dB } (\mu\text{V/m})$$

and the minimum field strength protected against this interference is

$$75{\cdot}5 + 8 = 83{\cdot}5 \text{ dB } (\mu\text{V/m})$$

whence the effective usable field strength taking both ground and skywave interference into account is

$$83{\cdot}5 + 2 = 85{\cdot}5 \text{ dB } (\mu\text{V/m})$$

The ground wave field strength of the wanted station at a distance of 30 km is (from Fig. 4)

$$72{\cdot}5 + 13 \text{ (for power)} = 85{\cdot}5 \text{ dB } (\mu\text{V/m})$$

and hence the service range in this direction is 30 km.

Corresponding calculations in the direction away from transmitter (i) indicate that the effect of the groundwave interference is negligible relative to the level of composite skywave interference.

3.4. Service area limited by skywave interference from members of synchronised group alone

If it is desired to quickly assess the usable field strength resulting solely from skywave interference due to other members of a synchronised group at distances between about 70 km and 500 km the following empirical formula derived from measurements and listening tests may be used:

$$E_p = 1{\cdot}2\sqrt{(P_1 + P_2 + P_3 \ldots \text{etc.})}$$

where E_p = usable field strength in mV/m of one of the transmitters in the group P_1, P_2 etc. are the effective radiated powers (kW) in the horizontal direction towards the reception point, of the other transmitters in the group. This method gives a rough estimate of service area limits to a standard appropriate for a programme such as popular music which is relatively resistant to interference.

4. Procedure for the determination of the sky-wave service area

It is sometimes necessary to estimate the range at which a given level of sky-wave, reflected from the ionosphere, would be received for a certain percentage of the time at night. This applies to l.f. and m.f. transmitters used for overseas broadcasts and the area so served is sometimes called the 'secondary' service area to distinguish it from the 'primary' or ground-wave service area but as already mentioned in Section 1 the use of the term 'secondary service area' is undesirable. Except in areas of the world near the magnetic equator the correction factors of CCIR Report No. 264–2[8] may be applied to the basic propagation curve of Fig. 14 having decided on the limits of field strength and percentage of time for which this limiting value must be provided. The purpose of these transmissions being generally for news or light entertainment broadcasts not requiring a high quality of reception or full freedom from background noise, it would typically be considered sufficient for a field strength of not less than 0·5 mV/m (54 dB rel. 1μV/m) to be available for 90% of the time. This corresponds approximately to a median field strength of 1 mV/m (60 dB rel. 1 μV/m). In the case of interference from a transmission also subject to fading, the range can be estimated as the distance at which a given protection ratio is exceeded as in Section 3.

---

*In this particular example the variation in the minimum field strength protected against skywave interference is less than ½ dB over the service area of the wanted station.

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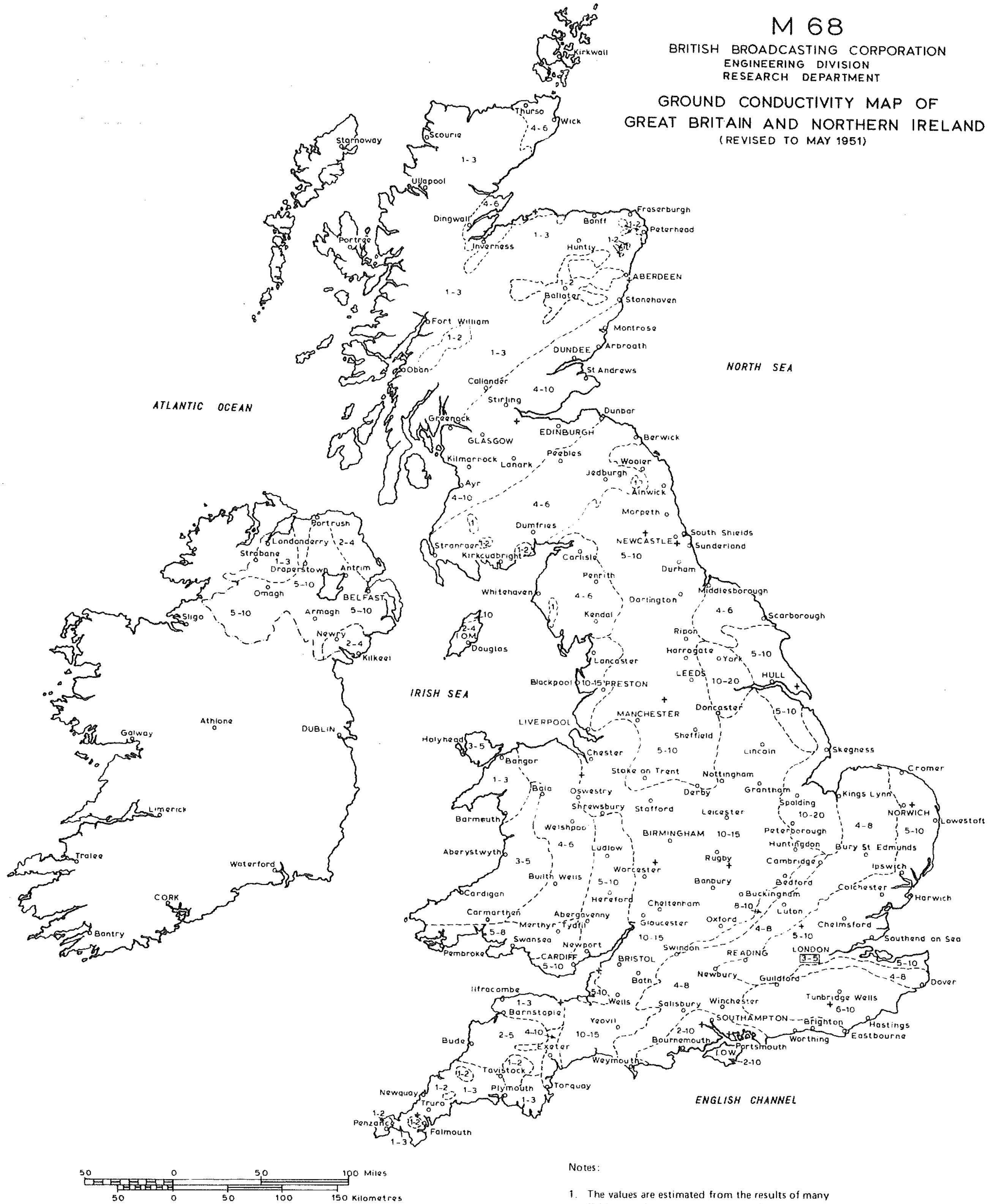


M 68
BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION
RESEARCH DEPARTMENT

GROUND CONDUCTIVITY MAP OF
GREAT BRITAIN AND NORTHERN IRELAND
(REVISED TO MAY 1951)

Topographical information based upon the
Ordance Survey map with the sanction of
the Controller of H.M. Stationery Office
'Crown Copyright Reserved'

Notes:

1. The values are estimated from the results of many field strength measurements made during site and service area surveys and from the known orographical features and geological formations
2. The values shown on the map apply to the frequency range 500 – 1500 kHz.
3. Effective conductivity values vary to some extent with frequency.
4. The conductivity values shown are in mS/m.

Fig. 1 - Ground conductivity map of Great Britain and Northern Ireland

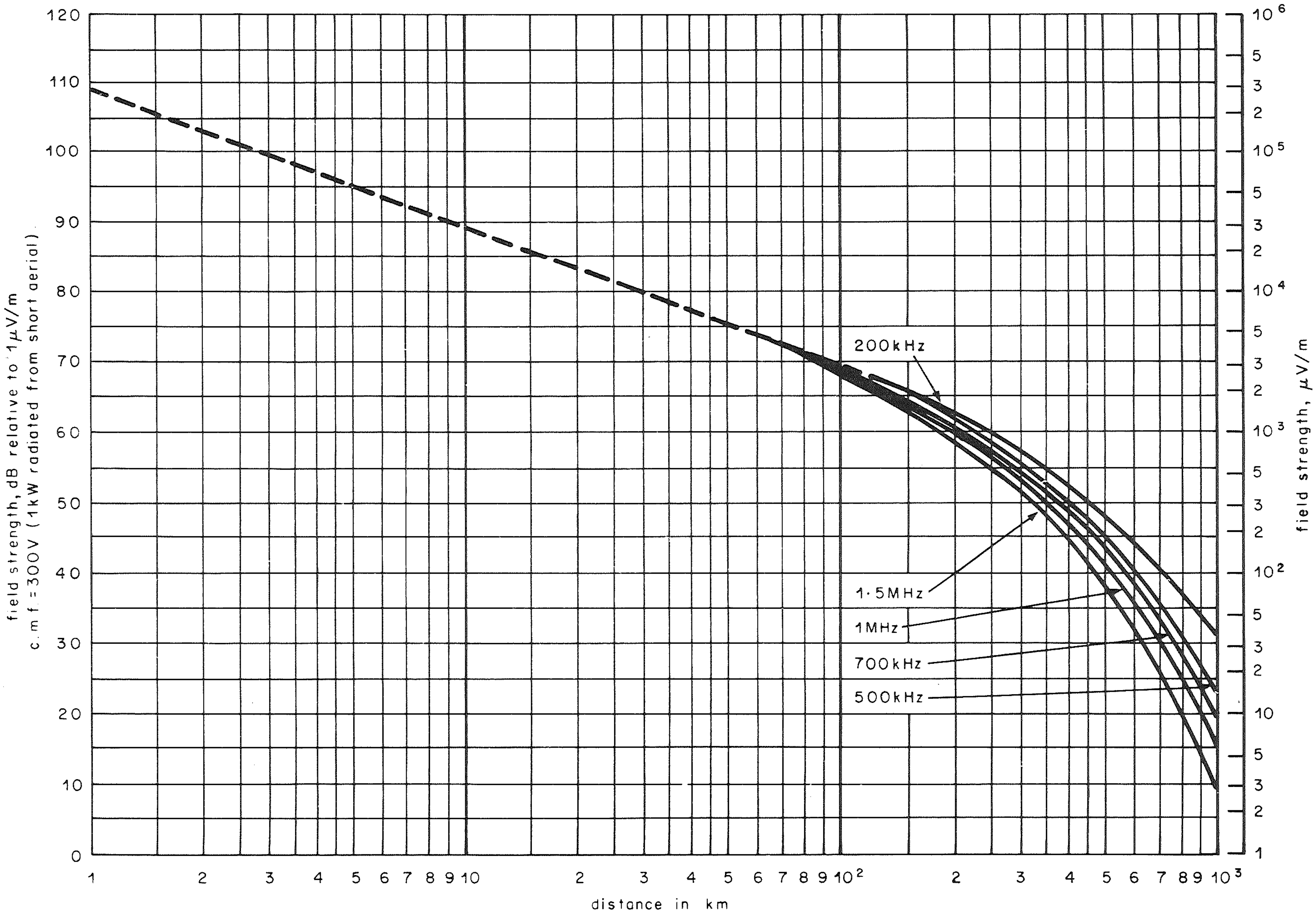


Fig. 2 - Groundwave propagation curves 200 kHz — 1·5 MHz
σ = 4 S/m, ϵ = 80 (sea-water)

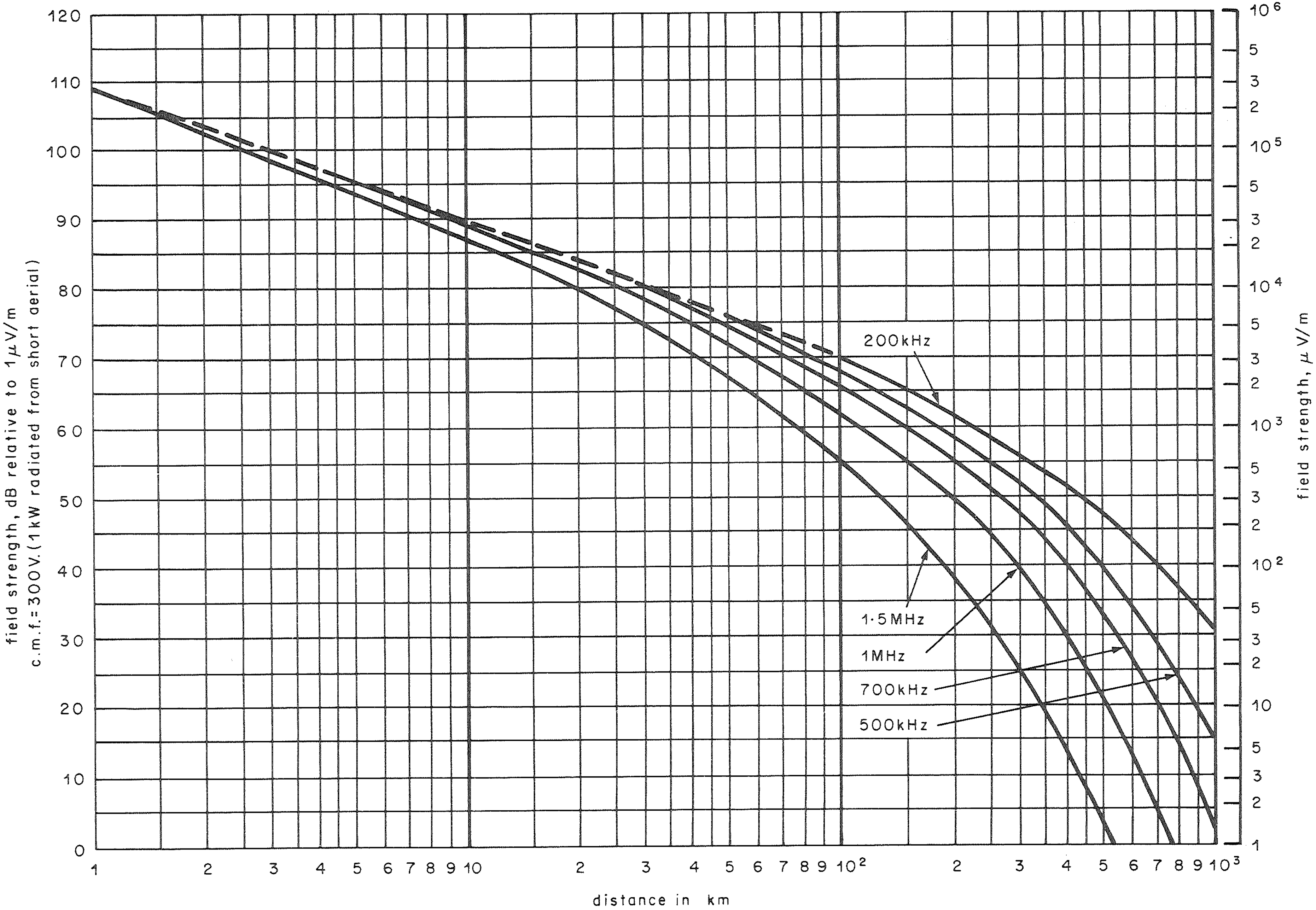


Fig. 3 - Groundwave propagation curves 200 kHz – 1·5 MHz
$\sigma = 3 \times 10^{-2}$ S/m, $\epsilon = 4$

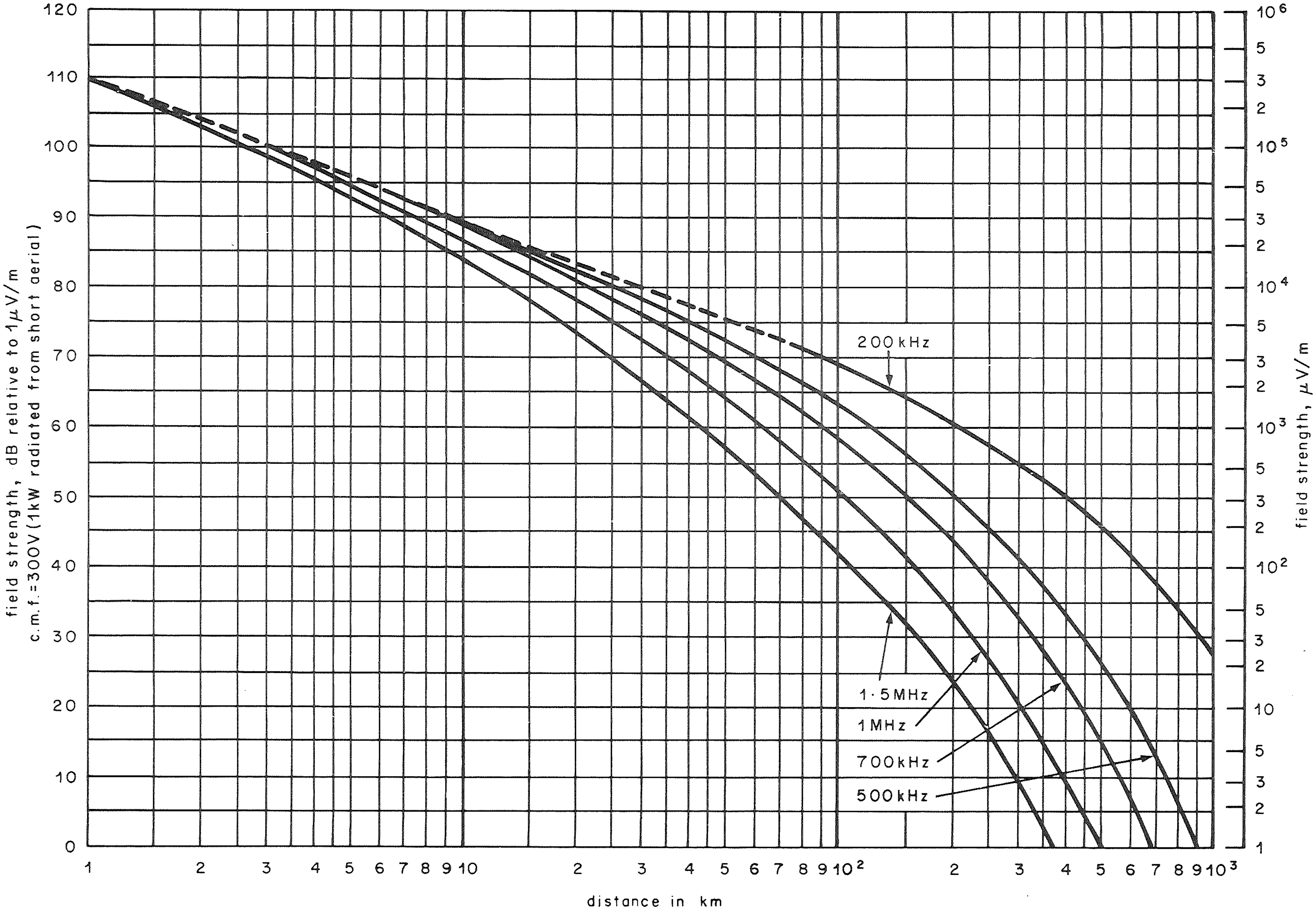


Fig. 4 - Groundwave propagation curves 200 kHz — 1·5 MHz
$\sigma = 10^{-2}$ S/m, $\epsilon = 4$

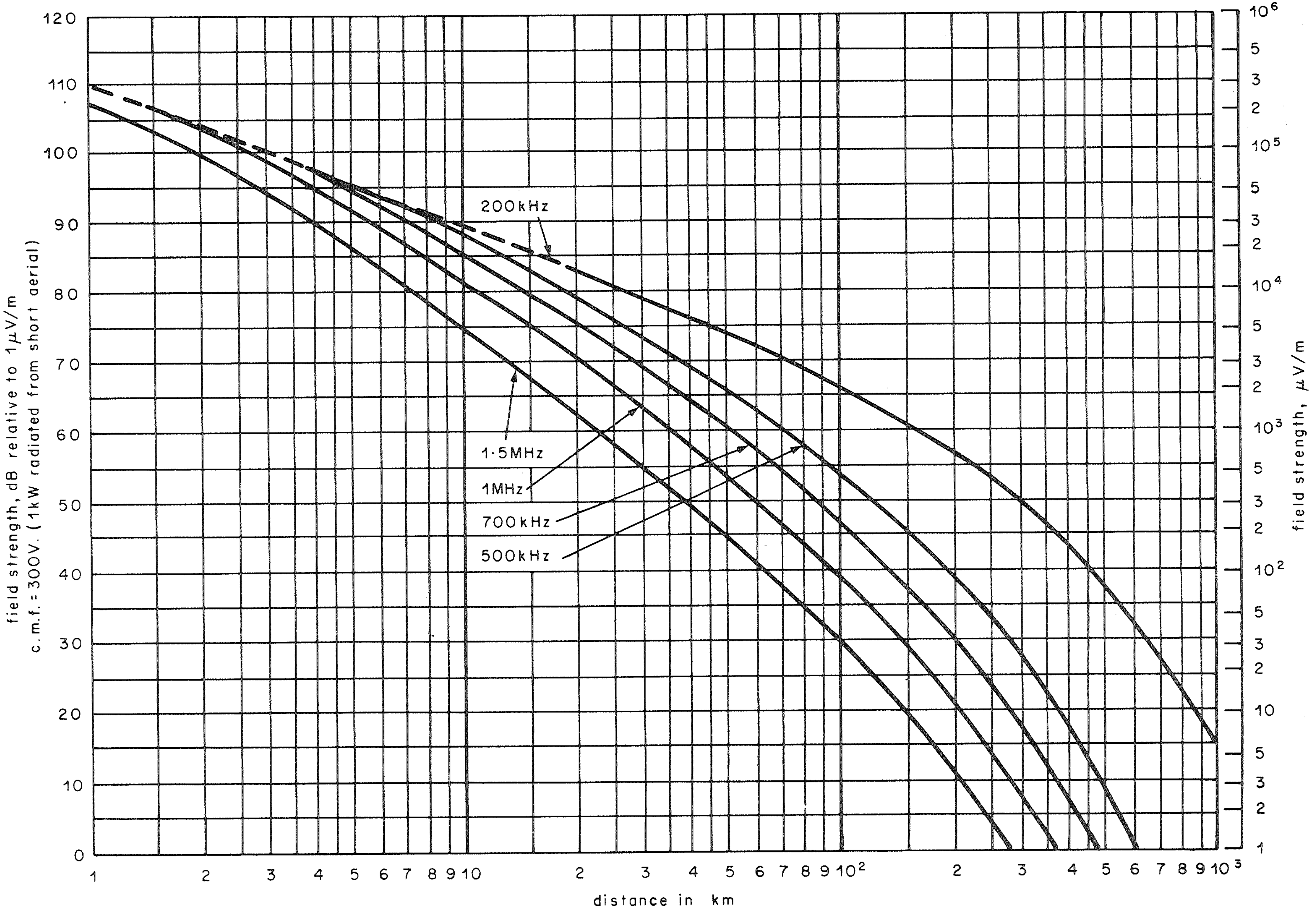


Fig. 5 - Groundwave propagation curves 200 kHz – 1·5 MHz
$\sigma = 3 \times 10^{-3}$ S/m, $\epsilon = 4$

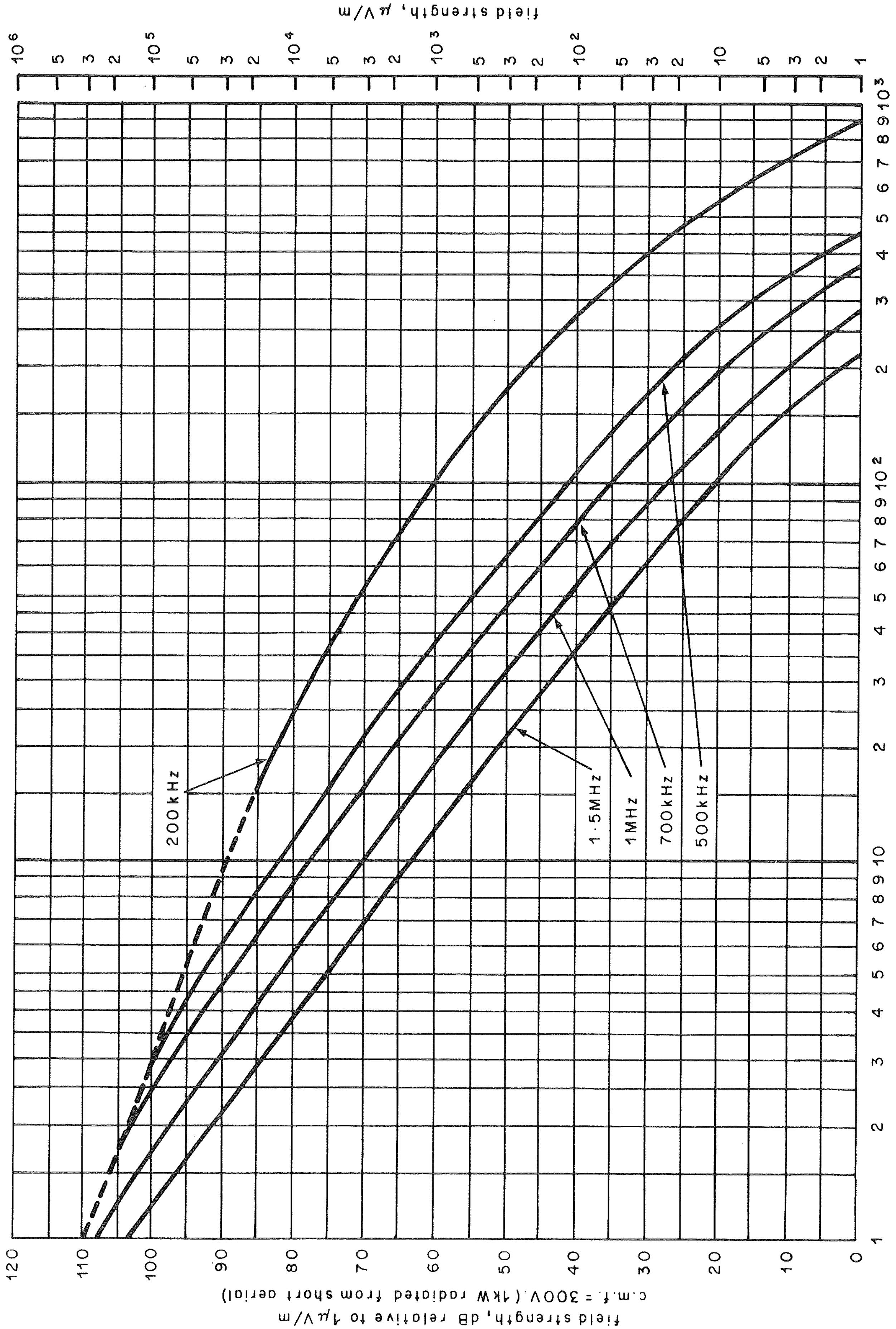


Fig. 6 - Groundwave propagation curves 200 kHz – 1·5 MHz

$\sigma = 10^{-3}$ S/m, $\epsilon = 4$

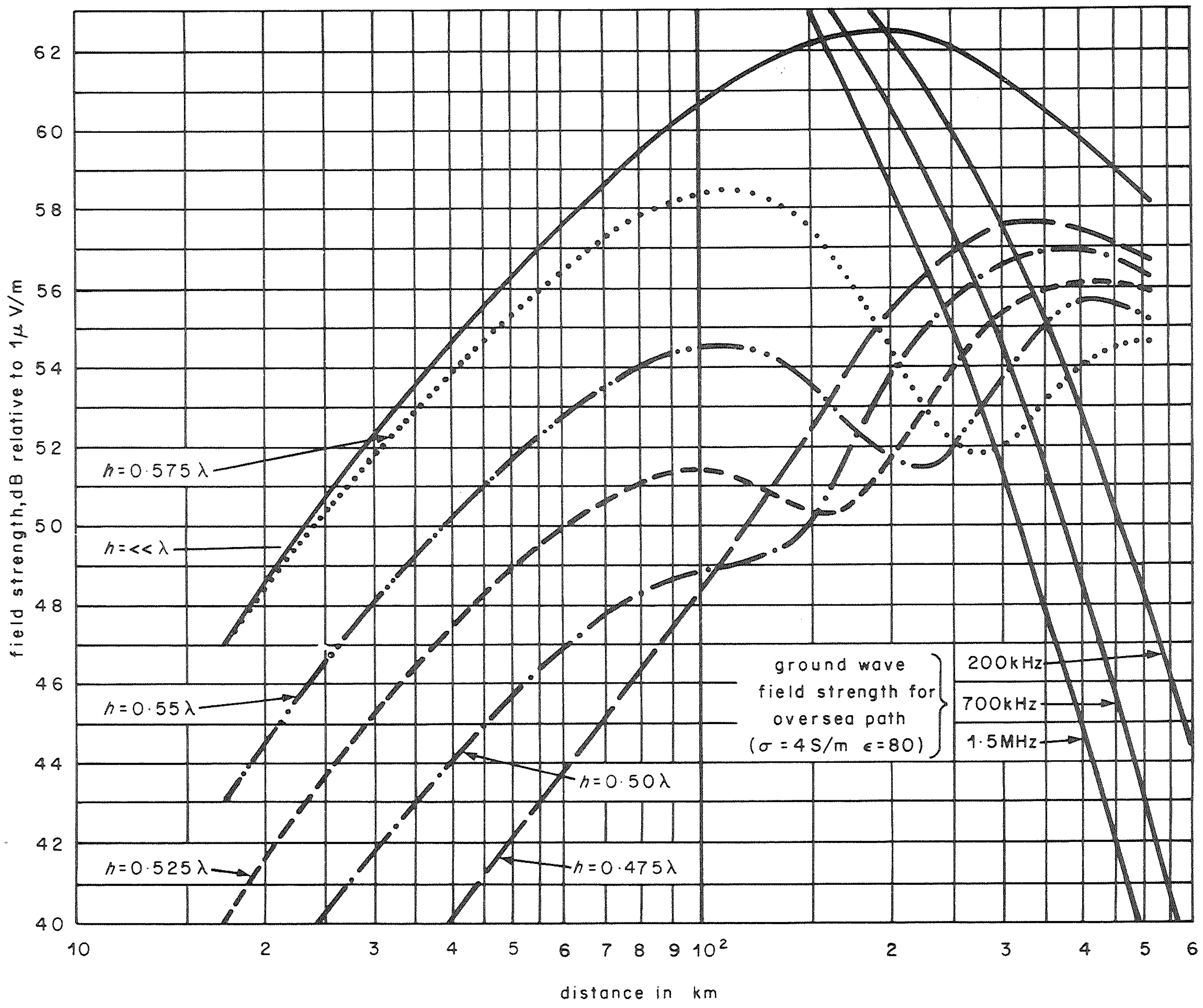


Fig. 7 - Skywave field strength from base-fed vertical transmitting aerial on ground of good conductivity
Layer height 100 km with unity reflection coefficient: ground reflection coefficient at receiving terminal 0·9
c.m.f. = 300 V; h is the physical height of transmitting aerial; loop receiving aerial

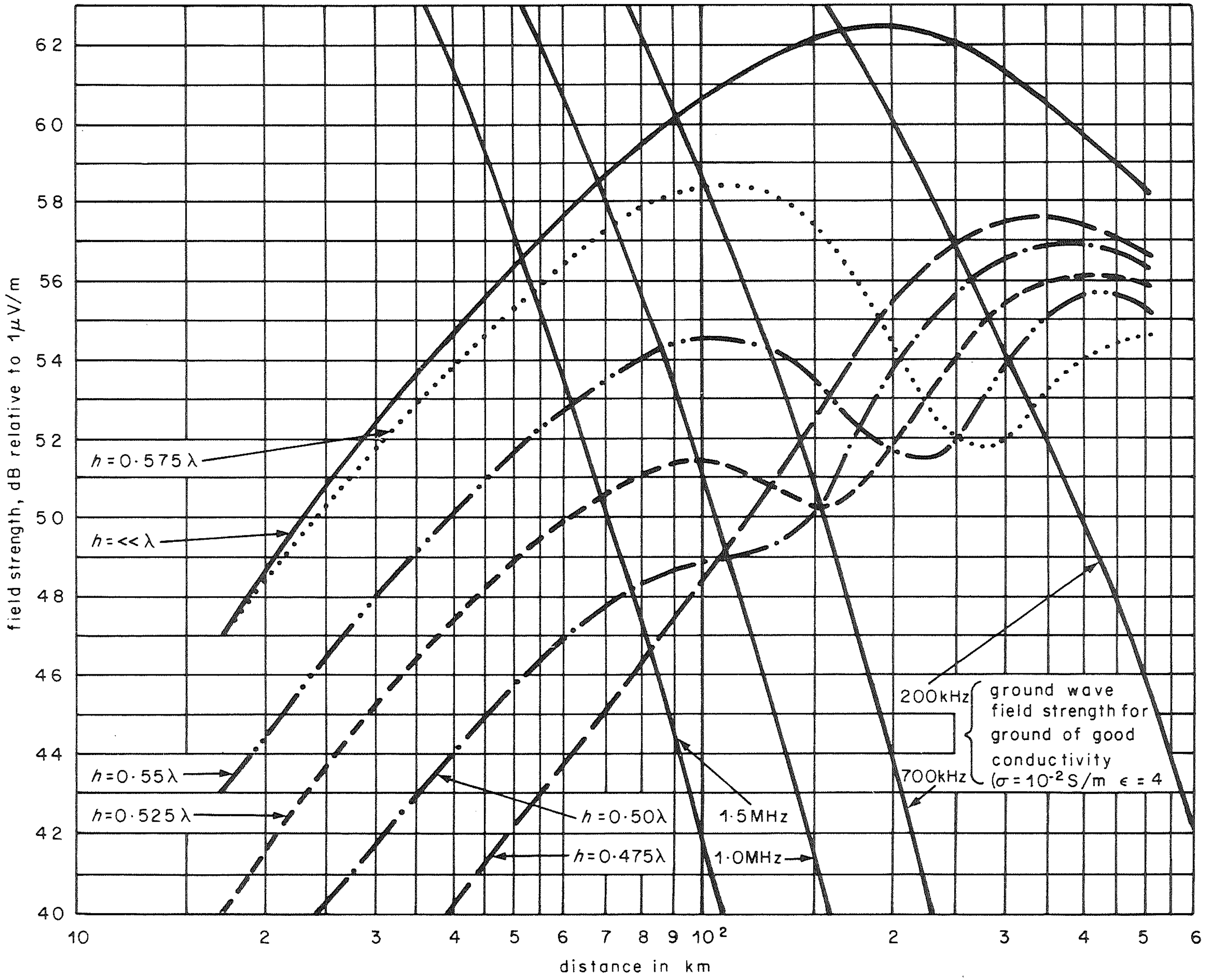


Fig. 8 - Skywave field strength from base-fed vertical transmitting aerial on ground of good conductivity
Layer height 100 km with unity reflection coefficient: ground reflection coefficient at receiving terminal 0·9
c.m.f. = 300 V: h is the physical height of transmitting aerial: loop receiving aerial

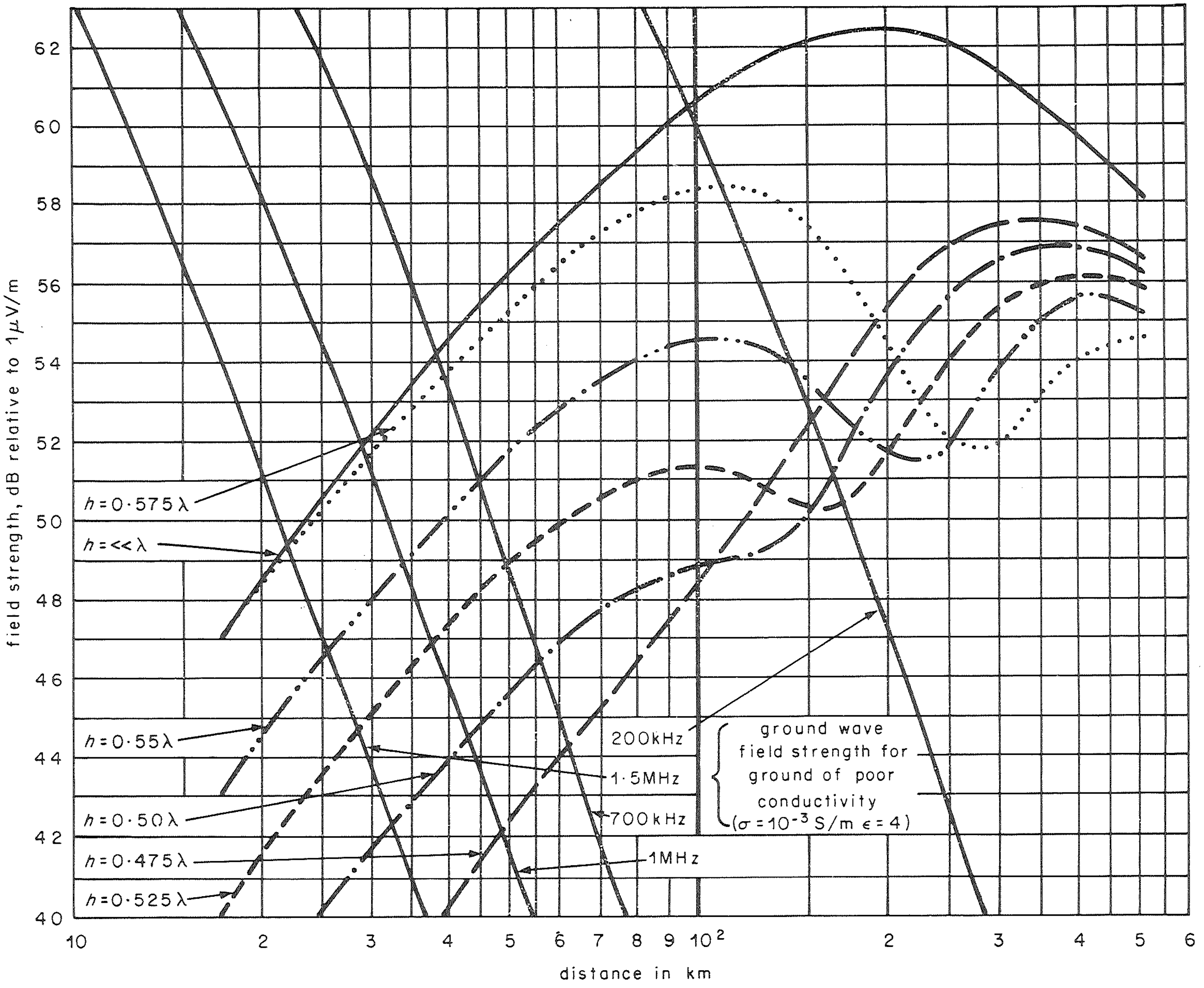


Fig. 9 - Skywave field strength from base-fed vertical transmitting aerial on ground of good conductivity

Layer height 100 km with unity reflection coefficient: ground reflection coefficient at receiving terminal 0·9

c.m.f. = 300 V; h is the physical height of transmitting aerial; loop receiving aerial

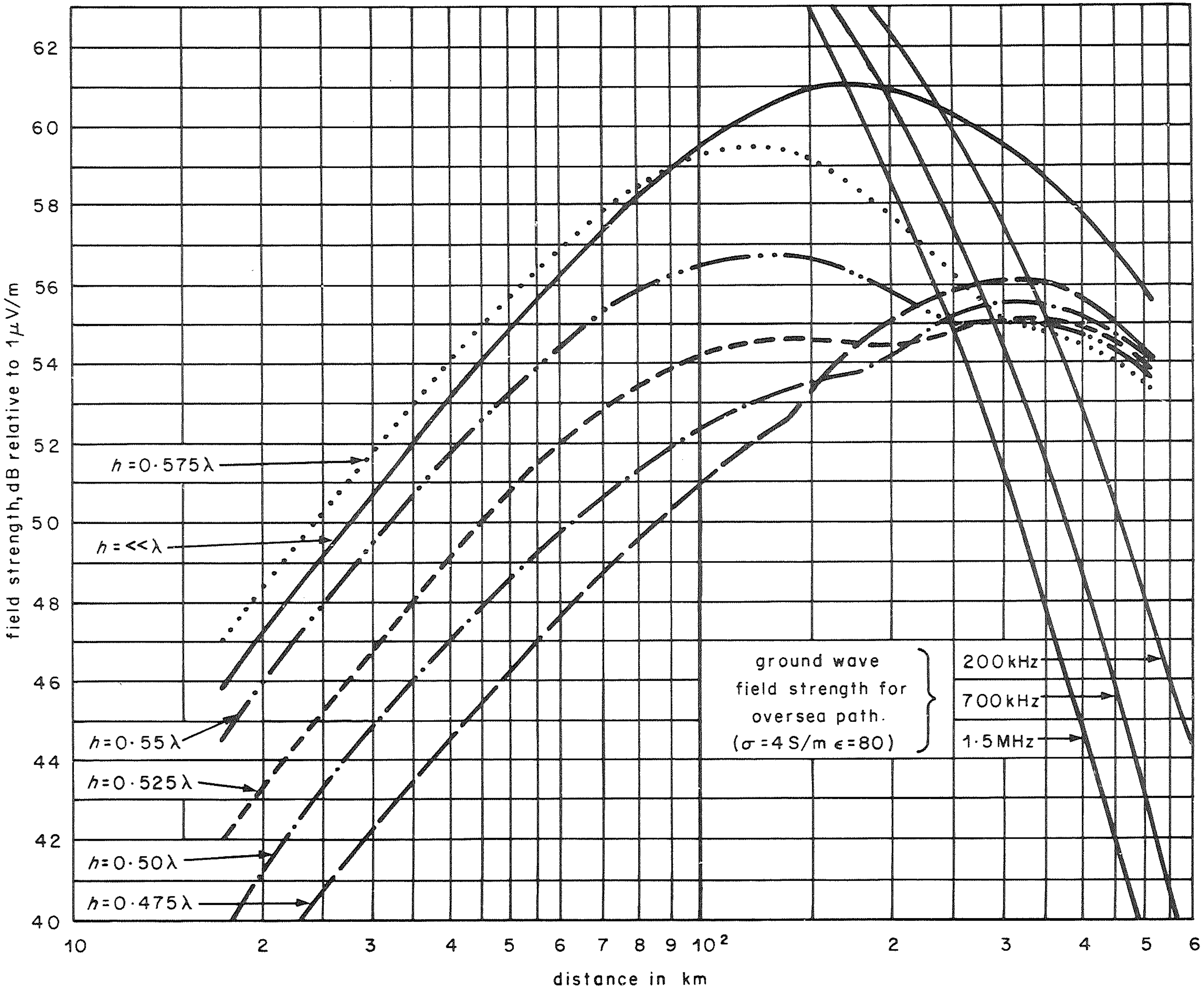


Fig. 10 - Skywave field strength from base-fed vertical transmitting aerial on ground of poor conductivity

Layer height 100 km with unity reflection coefficient: ground reflection at receiving terminal 0·9 c.m.f. = 300 V;
h is the physical height of transmitting aerial; loop receiving aerial

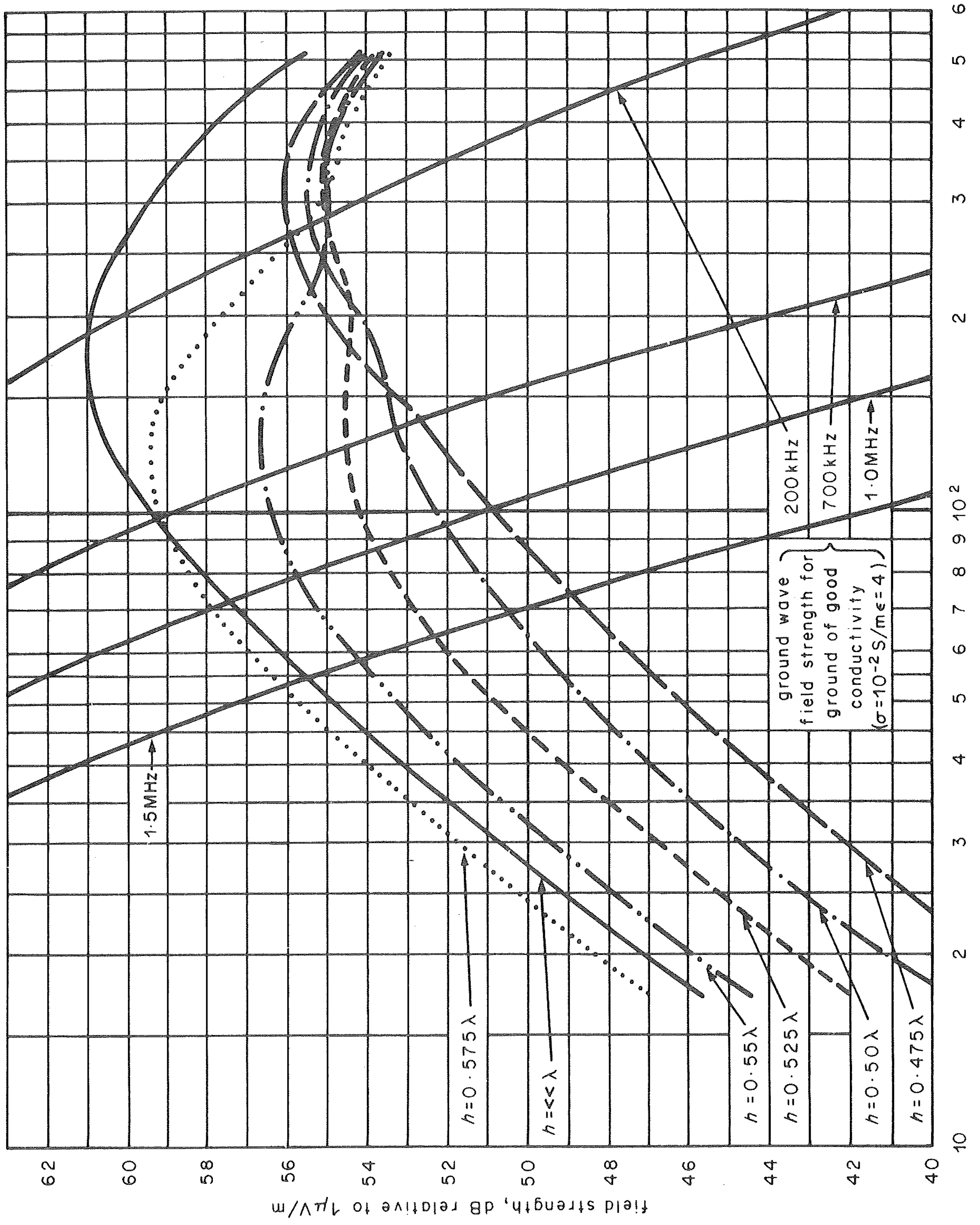


Fig. 11 - Skywave field strength from base-fed vertical transmitting aerial on ground of poor conductivity
Layer height 100 km with unity reflection coefficient: ground reflection coefficient at receiving terminal 0·9
c.m.f. = 300 V; h is the physical height of transmitting aerial; loop receiving aerial

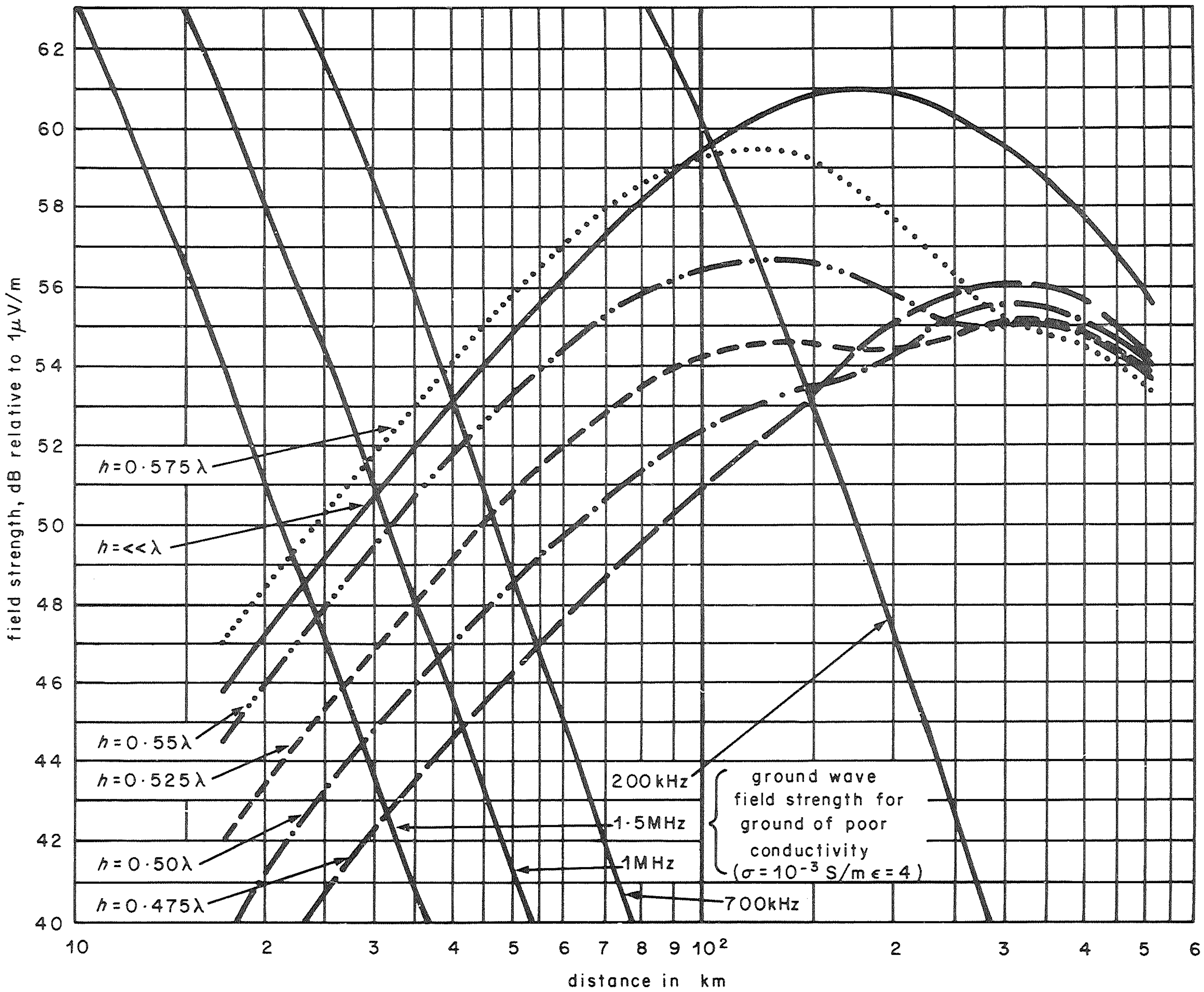


Fig. 12 - Skywave field strength from base-fed vertical transmitting aerial on ground of poor conductivity
Layer height 100 km with unity reflection coefficient: ground reflection coefficient at receiving terminal 0·9
c.m.f. = 300 V; h is the physical height of transmitting aerial; loop receiving aerial

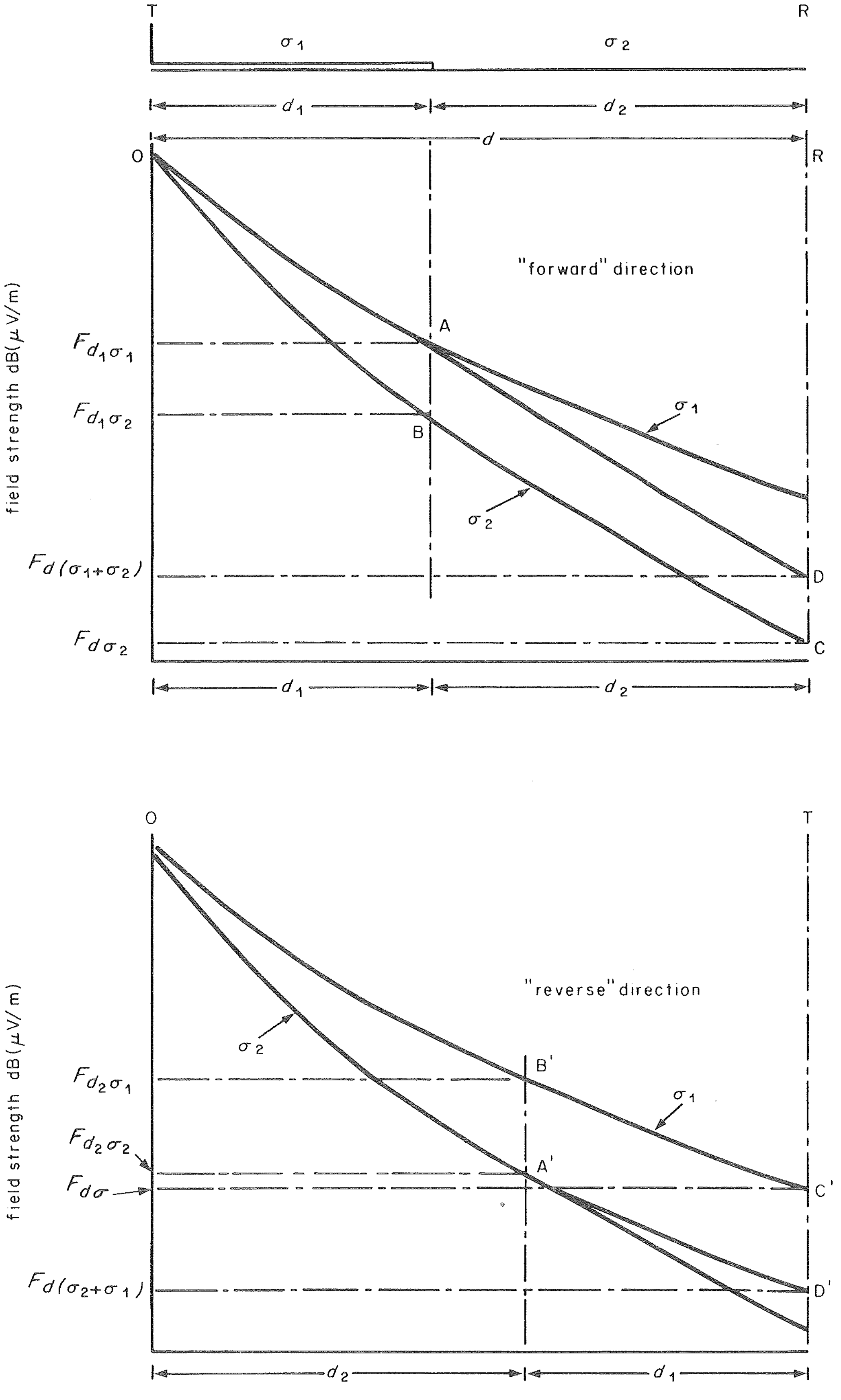


Fig. 13 - Application of the Millington method for mixed path calculation

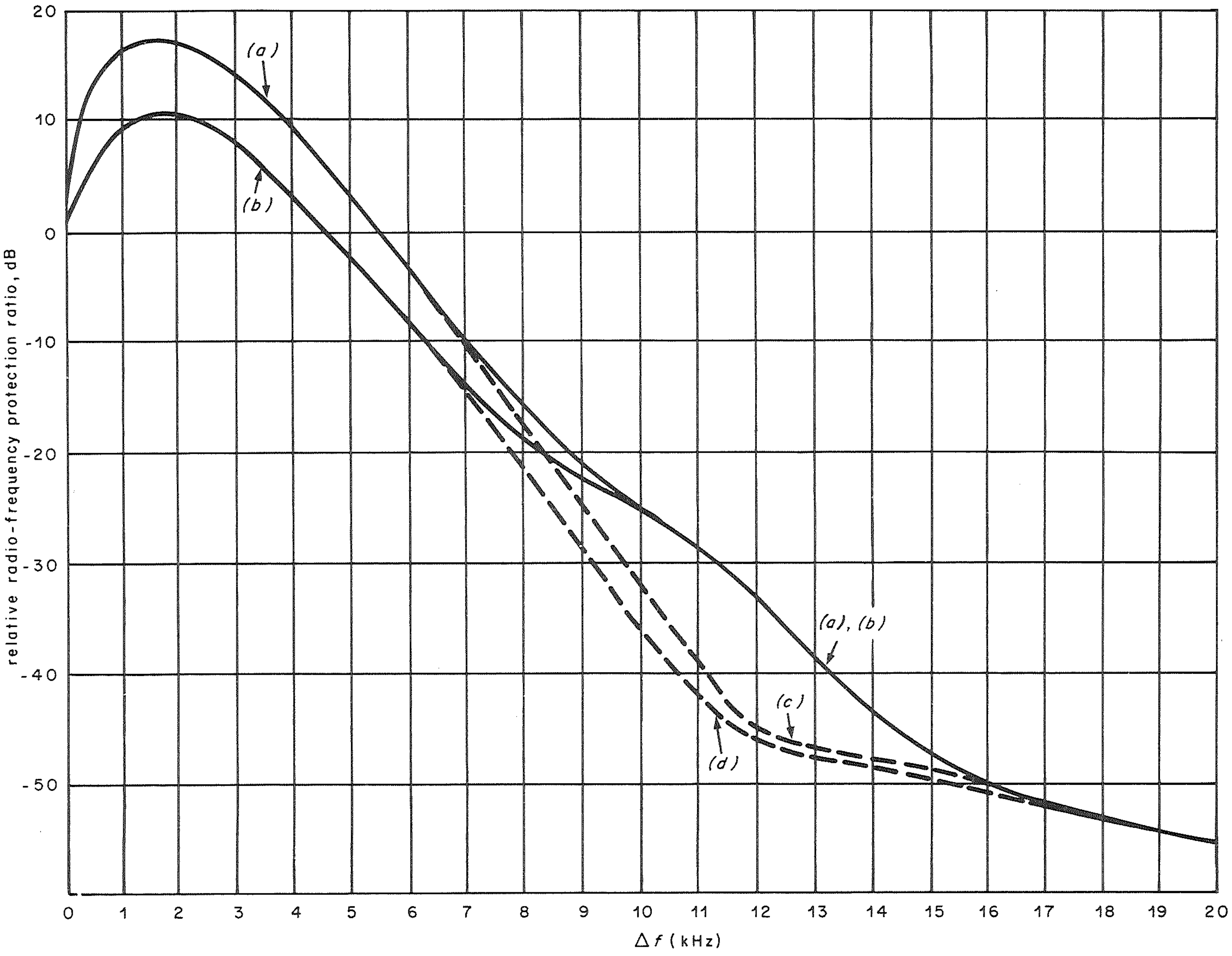


Fig. 14 - Relative value of the radio-frequency protection ratio as a function of the frequency separation between a stable wanted and a stable or fluctuation unwanted signal

Curve (a) applies when a limited degree of modulation compression is applied at the transmitter input, such as in good-quality transmissions, and when the bandwidth of the transmitted audio-frequency signal is of the order of 10 kHz. Curve (b) applies when a high degree of modulation compression (at least 10 dB greater than in the preceding case) is applied by means of an automatic device and when the bandwidth of the transmitted audio-frequency signal is of the order of 10 kHz. Curve (c) applies when a limited degree of modulation compression (as in the case of curve (a)) is applied and when the bandwidth of the transmitted audio-frequency signal is of the order of 4·5 kHz. Curve (d) applies when a high degree of modulation compression (as in the case of curve (b)) is applied by means of an automatic device and when the bandwidth of the transmitted audio-frequency signal is of the order of 4·5 kHz.

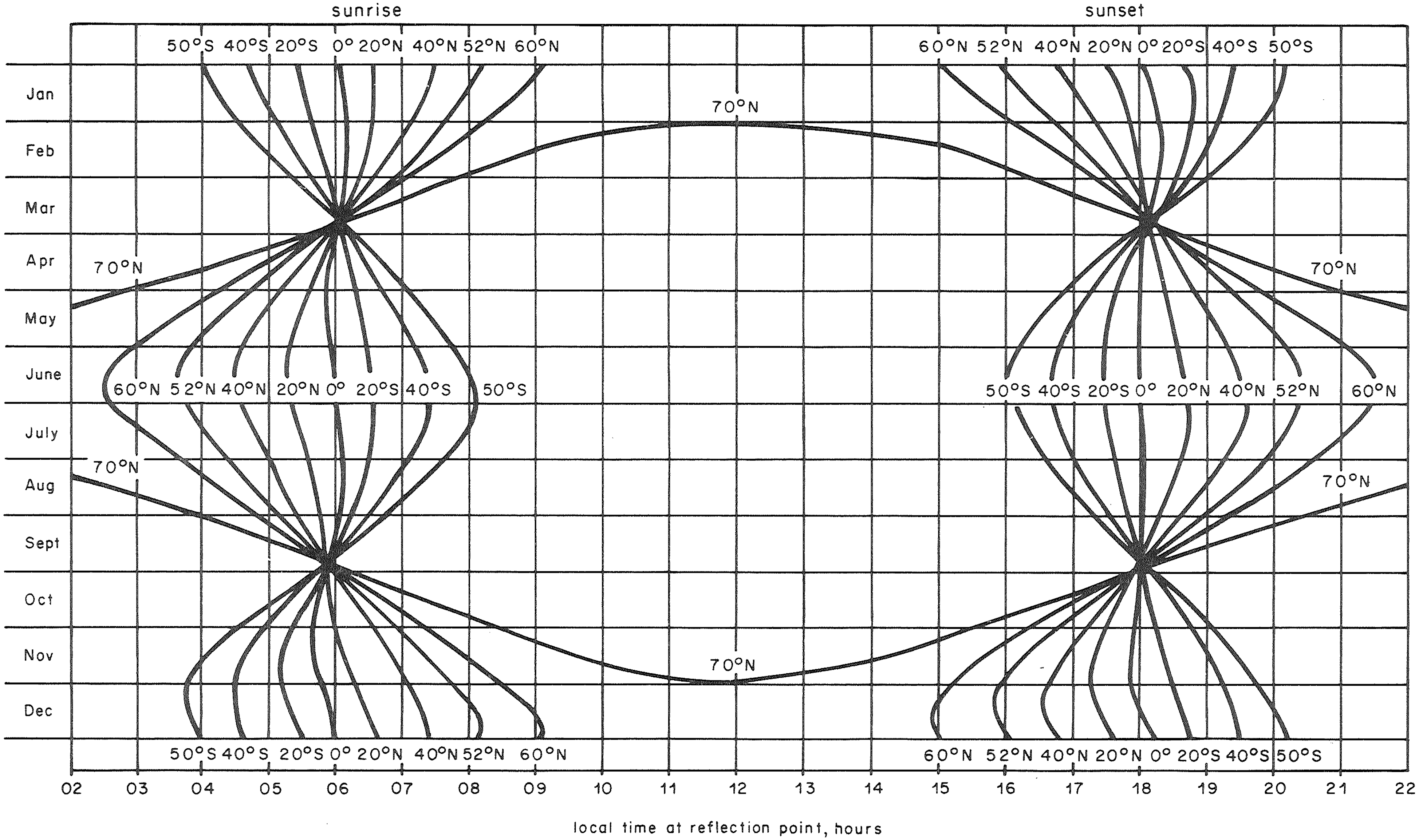


Fig.15a - Correction for diurnal and seasonal variations of skywave signals

Seasonal variation in times of sunrise and sunset as a function of geographic latitude

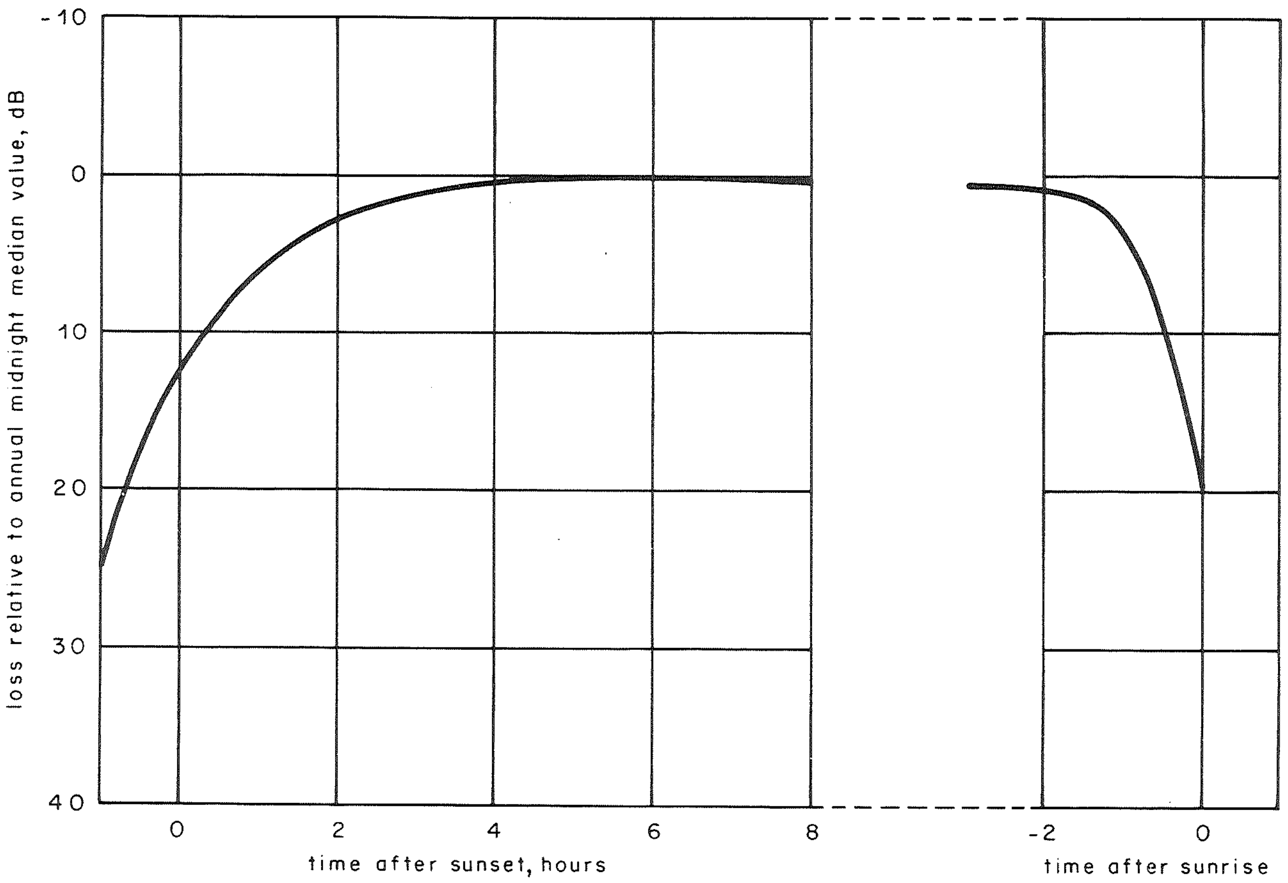


Fig. 15 b - Correction for diurnal and seasonal variations of skywave signals

Diurnal variation of skywave field strength

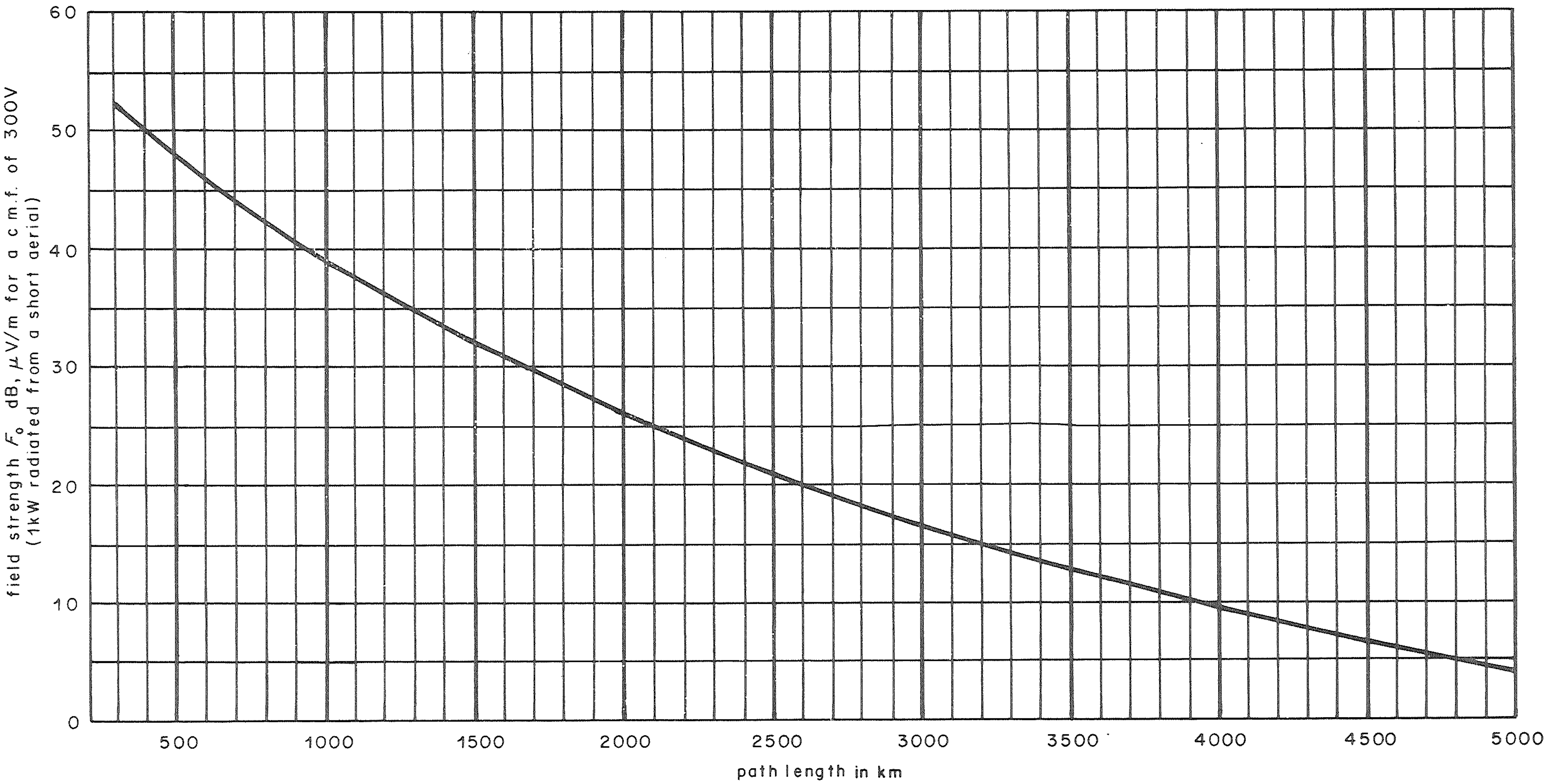
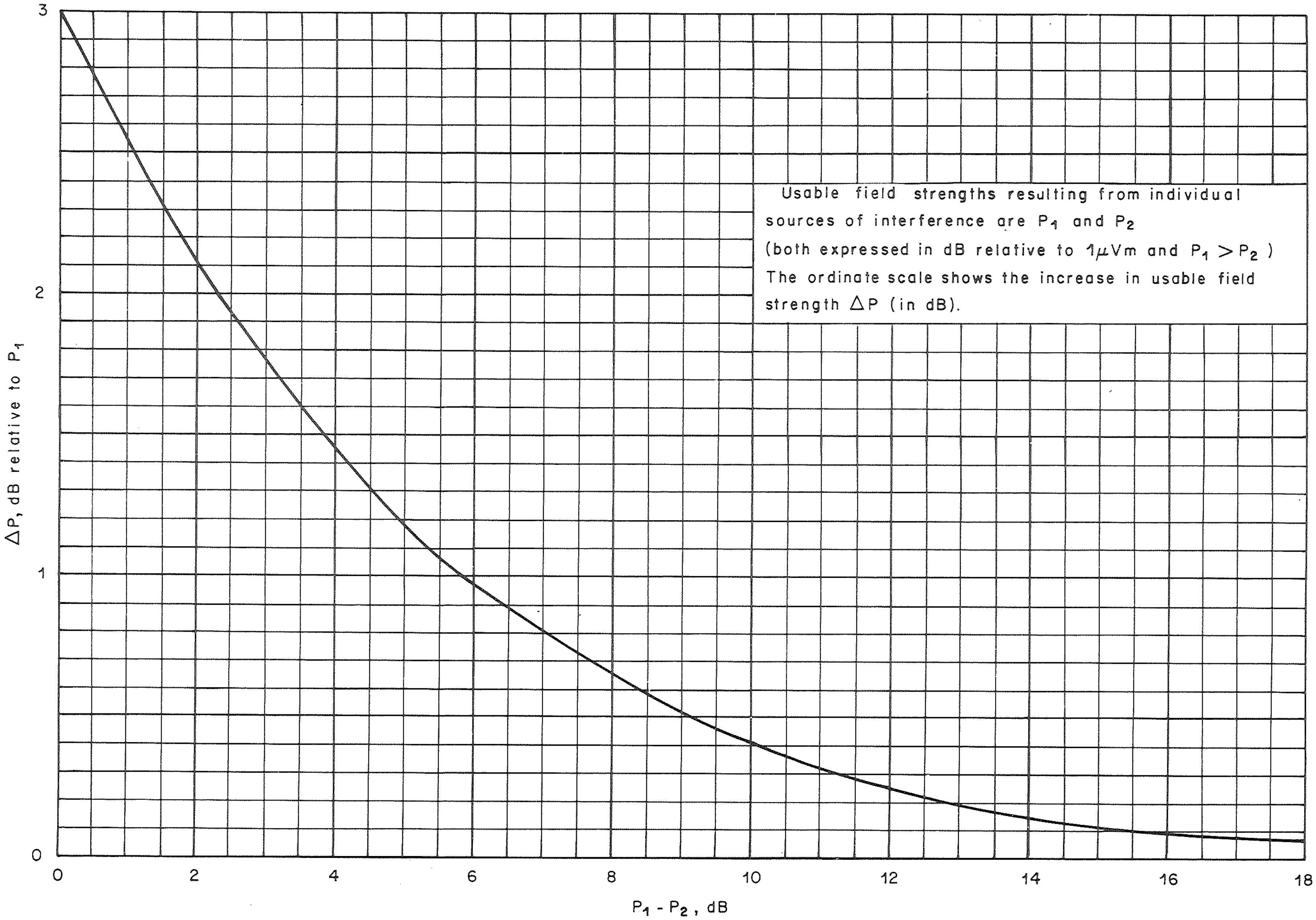


Fig. 16 - EBU empirical m.f. skywave propagation curve

$$F_o = \frac{396}{4 + D} - 40$$

where F_o is field strength (dB, µV/m for 1 kW)   D is path length (Mm)



Usable field strengths resulting from individual sources of interference are P_1 and P_2 (both expressed in dB relative to 1μVm and $P_1 > P_2$) The ordinate scale shows the increase in usable field strength ΔP (in dB).

Fig. 17 - Increase in usable field strength resulting from the addition of two interfering signals

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